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How do streetcar transit users and streetcar decision-makers perceive heat risk?

Ida Sami*, Ladd Keith

School of Landscape Architecture and Planning, University of Arizona, Tucson, AZ 85721, USA

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ABSTRACT

The thermal comfort perceptions of transit users at streetcar stops are critical to their overall ridership experience and health. Extreme heat is increasing due to climate change and the urban heat island effect, exposing transit users to greater heat stress. Through a survey of streetcar users and interviews with streetcar decision-makers, we explored the outdoor thermal comfort perceptions and transit stop design preferences of the Sun Link streetcar in Tucson, Arizona. Perceptions of heat among streetcar users varied by stop, with survey data revealing that 82.4 % of users reported feeling hot at the stops. Additionally, 56.08 % of users surveyed reported that more shade and trees would improve their thermal comfort. Heat risk is recognized by most decision-makers at Sun Link streetcar, primarily for their employees but also for users. Decision-makers reported needing additional resources to address transit user heat risk. We recommend increased awareness about extreme heat and heat resilience strategies at the stops, such as more shade and more frequent service, to help improve users' thermal experience. Other transit systems facing increasing heat should also consider increasing heat risks and the thermal comfort perceptions of their users.

1. Introduction

Heat is increasing in cities worldwide due to climate change and the urban heat island (UHI) effect. While heat impacts many urban systems, it particularly and often inequitably impacts public health. Heat is the leading weather-related killer in the United States (U.S.), with between 600 and 1800 deaths each year due to extreme heat (Uejio et al., 2011). Public transit is critical to increasing heat risk as it can help where cities can reduce the vehicle-related greenhouse gas emissions causing climate change and also reduce vehicle waste heat that contributes to the UHI effect. Public transit is also impacted by increasing heat, as rising temperatures expose transit users waiting at stops to unsafe thermal conditions and can lead to heat-related illness. To encourage more people to use public transportation and mitigate climate change, transit operators should ensure their systems are heat resilient, both mitigating heat at the stops and managing heat through operations. This study explores perceptions of thermal comfort with the Sun Link Streetcar system and transit stop design preferences in Tucson, Arizona, through surveys of users and interviews with decision-makers.

1.1. Planning for extreme heat

Climate change provides significant challenges to preserving and enhancing global health and well-being (Sheffield and Landrigan, 2011). As a result of climate change, average temperatures are rising, increasing the risk of extreme heat events (Sheffield and Landrigan, 2011). Extreme heat can be higher in urban areas due to the urban heat island (UHI) effect (Oke, 1973). The UHI effect is caused by the built environment's design and associated building and vehicle waste heat (Ferwati et al., 2018). The UHI effect increases the temperature in cities compared to surrounding rural areas, particularly at night, when the difference may be as high as 7.2 °F (4 °C) (Oke, 1973; Yang et al., 2016; Stone et al., 2019).

Extreme heat events can be defined as, "weather that is substantially hotter and/or more humid than the normal average for a location at that time of year" (White-Newsome et al., 2014). Extreme heat often inequitably impacts low-income communities (EPA, 2017). Extreme heat events result in more deaths compared to other weather disasters (Huang et al., 2011). Recent extreme heat waves have caused severe health, economic, and social problems in Europe, the U.S., and southeast Australia, particularly in urban areas (Robine et al., 2008;

* Corresponding author.
E-mail addresses: idasammi@gmail.com (I. Sami), ladd@arizona.edu (L. Keith).

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Vaidyanathan et al., 2020). Such events will continue to add additional challenges to health risk management, emergency response systems, and the reliability of the power supplies and other infrastructure (Loughnan et al., 2012). In the U.S., the total number of deaths resulting from excessive heat is more than the number due to other natural hazards (Vaidyanathan et al., 2020; Thacker et al., 2008). The increasing prevalence of extreme heat will cause more problems for public and individual health around the world (Sheffield and Landrigan, 2011).

1.2. Thermal comfort of transit users

Public transit is a critical component of reducing greenhouse gas emissions in cities (Iamtrakul and Zhang, 2014). Because of this, U.S. laws and initiatives such as the SAFETEA Act and Moving Ahead for Progress in the 21st Century Act have fostered the expansion of public transportation infrastructure and transit use (Fraser and Chester, 2017). However, increasing impacts of climate change and the frequency and severity of extreme weather events such as extreme heat, harm both public transportation infrastructure and transit users comfort and health (Rocha et al., 2020; Kovats and Hajat, 2008). Heat waves are often called a “silent killer” because, unlike other natural disasters, extreme heat events often do not leave a visable path of destruction (Loughnan, 2014; Carroll, 2002). Despite this, extreme heat causes short- and long-term problems for public transportation systems and public transit users (Fraser and Chester, 2017).

Public transportation has many advantages, such as lowering carbon emissions (Dzyuban, 2020; DeCorla-Souza and Jensen-Fisher, 1994; Aston et al., 2020), but it can also raise health concerns during times of extreme heat (Chow et al., 2012a; Aston et al., 2020). Excessive exposure to high temperatures has direct health impacts, including heatstroke, heat exhaustion, heat cramps, and, leading to further urgent care and emergency room visits, hospitalizations, and early mortality (Huang et al., 2011; Yoo et al., 2021). Heat-related illnesses and deaths are more likely to occur early in the summer when temperatures are high and physiological and behavioral adaptations have not yet been established (Vanos et al., 2015). Low-income communities are also more likely to be exposed to the heat due to their reliance on public transit than people who own personal vehicles (Dzyuban, 2020; Markolf et al., 2019).

Predicting and evaluating ridership data are key components of most heat and public transportation studies (Grahn et al., 2021; Kuby et al., 2004; Arana et al., 2014; Wei, 2022). These studies, however, do not include the impact of extreme heat on the remaining transit users who may have no other alternatives for required travels (Markolf et al., 2019; Thani et al., 2012). The built environment can affect human outdoor thermal comfort under extreme heat conditions (Middel et al., 2014). Based on a study by Ashrae55 (2004), thermal comfort is “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.” Outdoor thermal comfort depends on several factors, including ambient temperature (air temperature), radiant temperature (the temperature of the surfaces around us), relative humidity (the measurement of the water vapor in an air-water mixture), air motion (the rate at which air moves around and touches the skin), metabolic rate (the amount of energy expended), and clothing insulation (materials used to retain or remove body heat) (Middel and Krayenhoff, 2019).

Heat perception plays a crucial role in influencing people's behavior in response to extreme temperatures. Prior research has shown that effectively communicating a clear definition of "heat" or "heatwaves" can impact how populations perceive and react to heat (ANON et al., 2021). Heat risk perception varies geographically and tends to be higher among vulnerable subgroups, such as low-income, minority, and individuals in poor health. Understanding public perceptions of heat-related risk and the factors motivating adaptive behaviors is essential for successful public health interventions under climate change (ANON et al., 2021, 2019)

Exposure to high temperatures can lead to various heat-related health issues. These include heat exhaustion, which can cause headaches, nausea, and vomiting (ANON et al., 2013; Gabriel and Endlicher, 2011) and heat stroke, a more severe condition that can lead to organ damage, seizures, or even death (ANON et al., 2016). Prolonged exposure to heat can also exacerbate pre-existing conditions, such as cardiovascular and respiratory illnesses (Smoyer et al., 2000; Howe et al., 2019). Moreover, studies have found that the perception of heat risk can significantly influence an individual's adaptive behaviors, such as seeking shelter, adjusting outdoor activities, or using indoor cooling methods (ANON et al., 2019). Targeted interventions that account for heat perception and its effects on behavior can help enhance public adaptation to extreme temperatures and better prepare communities for ongoing climate changes (Keith and Meerow, 2022a)

In thermal perception research, qualitative approaches are often used to explore subjective experiences (ANON et al., 2021, 2019). Such methodologies are necessary to provide a complete picture of thermal perception. Physiological methods can only explain about half of the difference between objective and subjective outdoor thermal perception (ANON et al., 2013). The other half of the variation is influenced by psychological factors (ANON et al., 2021; Gabriel and Endlicher, 2011). The perception of heat may also be influenced by a variety of other elements, such as culture or the environment that individuals are adapted (ANON et al., 2021, 2016).

1.3. Planning for heat-resilient transit systems

As heat increases, cities across the world are seeking to address heat (Smoyer et al., 2000; Howe et al., 2019). Extreme heat can stress human physiology and public transportation infrastructure by expanding rails. It can also cause overhead power supply lines to lose tension (Sheffield and Landrigan, 2011; Aston et al., 2020). Heat resilience is the key to helping transit systems to be more prepared for extreme heat. Heat resilience includes heat mitigation and heat management (Howe et al., 2019). Heat mitigation refers to strategies aimed at reducing the built environment’s contribution to urban heat. Heat management refers to strategies that address chronic and acute heat risk. Cities and communities can implement heat mitigation and management measures to prepare for and adapt to increasing heat risk (Howe et al., 2019; Nikolopoulou et al., 2001a).

Designing heat-resilient transit stops is crucial for promoting urban heat resilience, especially in cities experiencing frequent heatwaves (Dzyuban, 2020; Smoyer et al., 2000). By incorporating urban form, materials, and waste heat emissions into bus stop design, comfortable and heat-resilient transit stops can be created that encourage public transportation use (Dzyuban, 2020; Keith and Meerow, 2022a). Effective strategies include green roofs or walls, light-colored materials, and natural ventilation, which reduce heat absorption and improve user comfort (Fraser and Chester, 2017; Aston et al., 2020; Smoyer et al., 2000). Dense urban forms with natural shading and ventilation, cooler materials for paving, walls, and roofs, and surrounding vegetation minimize heat absorption and enhance air quality.

Proper shelter placement in shaded areas, away from high traffic and heat sources, is essential for reducing heat absorption and improving the comfort of transit users (Dzyuban, 2020; Howe et al., 2019). Providing clear signage and seating at transit stops not only improves the transit experience but also reduces the risk of heat-related illnesses for users (Keith and Meerow, 2022a). Promoting public transport over private vehicles and implementing energy-efficient systems further reduces waste heat emissions (Keith and Meerow, 2022a). These heat mitigation strategies foster sustainable, livable urban environments while enhancing user comfort and public health outcomes.

Heat resilience is relevant to alternative modes of transportation, such as transit systems, as heat negatively impacts both transportation infrastructure and travelers (Dzyuban, 2020). This includes bike- and pedestrian-friendly paths, transportation use, and the design of public transit stops (Nikolopoulou et al., 2001a; Lenzholzer et al., 2018). Heat resilience strategies may provide more shade at stops and along pedestrian paths, and operations can be more frequent to reduce the time spent waiting (Keith and Meerow, 2022b). To explore the perceptions of the thermal comfort of transit users and their preferences of design elements of the stops, we conducted a survey of Sun Link streetcar users in Tucson, AZ. We also conducted interviews with Sun Link streetcar decision-makers to better understand their challenges and opportunities in addressing heat risk.

2. Material and methods

In this study, we use a qualitative research approach and conducted a survey of Sun Link Streetcar users and semi-structured interviews with streetcar decision-makers in Tucson, Arizona.

2.1. Study context

The City of Tucson is located in the Sonoran Desert in the U.S. Southwest, with hot, semi-arid climate. The region is predicted to see an 8.6 ˚F (4.8 ˚C) rise in annual average temperature by 2100 under high-climate projection scenarios such as RCP 8.5 (Gonzalez et al., 2018). The City of Tucson has a population of 543,242 (U.S. Census Bureau, 2021) and is also the third-fastest-warming city in the U.S., followed by Las Vegas, Nevada, and El Paso, Texas, with a 4.48 ˚F (2.49 ˚C) rise in temperature (U.S. Global Change Research Program, 2018). Tucson's annual temperature typically varies from 42 ˚F (5.5 ˚C) to 102 ˚F (38.8 ˚C) and is rarely below 33 ˚F (0.5 ˚C) or above 107 ˚F (41.6 ˚C). Arizona had 520 heat-related fatalities in 2020, up 62 % from 2019 (Keith and Meerow, 2022b).

Tucson developed the Sun Link Streetcar to help achieve sustainability goals. The 3.9 mile streetcar route has 23 stops and connects five districts with distinct urban typologies: the University of Arizona, Main Gate Square, Fourth Avenue, Downtown, and the Mercado (Sun Link, 2018). The 23 streetcar stops were designed with solar orientation in mind and most include shade structures and light-colored seating to reduce heat.

The streetcar annual ridership was 896,991 trips in 2019, decreased due to COVID-19, to approximately 150,000 trips in 2020, and began increasing again after free fare was initiated (Meerow and Keith, 2021; Chow et al., 2012b).

2.2. Survey of streetcar users

Outdoor thermal comfort phenomena are complicated and need a comprehensive approach to investigate since they are dependent on each individual's lived experiences (Dzyuban, 2020; Middel and Krayenhoff, 2019; Gabriel and Endlicher, 2011; Dzyuban et al., 2017). A survey is a frequent tool for studying perceptions of outdoor thermal comfort since it can capture people's subjective responses to their environments (Gonzalez et al., 2018; U.S. Census Bureau, 2021). We refined a thermal comfort survey using questions from several past studies (Dzyuban, 2020; Middel and Krayenhoff, 2019; Lenzholzer et al., 2018). The survey included questions covering streetcar users' thermal experiences at stops and their subjective thermal perceptions of corresponding microclimatic conditions. We also surveyed users on their use of the streetcar, their changes in riding the streetcar during hot weather, their demographics, and household income (see Appendix A for the complete survey).

Due to COVID-19 pandemic restrictions, we deployed the survey to reach streetcars users online through flyers on social media and through stakeholder networks from October 2021 to January 2022, notably in the coolest season for Tucson. Sun Link Streetcar operators also published the survey on their social media accounts, to reach their ridership. Survey responses were analyzed using the analysis of variance (ANOVA) method, resulting in descriptive statistics (Naik and Reddy, 2018).

Table C1
Semi-structured interview questions.

1. Does extreme heat impact the Sun Link Streetcar employees or users? If so, how?
2. Does extreme heat impact the Sun Link Streetcar physical infrastructure and system? If so, how?
3. Do Sun Link Streetcar operations change during periods of extreme heat?
4. Do you have any programs or collaborations related to extreme heat awareness for users or Sun Link streetcar employees? If yes, please describe.
5. What extreme heat information sources have you used?
6. What would extreme heat information be useful?
7. Are there any barriers to addressing extreme heat for the Sun Link Streetcar?
8. What design features of the Sun Link Streetcar stops do you like? Why?
9. What design features of the Sun Link Streetcar stops would you like to modify? Why?
10. How has COVID-19 impacted the Sun Link Streetcar operations?

2.3. Interviews with streetcar decision-makers

We also conducted semi-structured interviews with streetcar decision-makers during the fall of 2021 for insights into the managers' and operators' perceptions of heat risk. Interview questions included topics such as heat impacts on streetcar employees, users, and physical infrastructure, changes in operations due to extreme heat, heat awareness programs, information sources, barriers and opportunities in addressing heat, and the design of stops (see Table C1).

We identified five interview candidates through both the snowball sampling method and by searching job titles on a publicly accessible government website. The interviewees all worked at the City of Tucson's Sun Link streetcar department as either supervisors or managers. These interviews were conducted over Zoom and were recorded and transcribed. Each interview was one-on-one and lasted between 15 and 30 min. We asked follow-up questions to enable participants to elaborate on or clarify subjects and ensure that all aspects of the discussion were covered. Participants were given a chance to follow up with additional comments after the interviews ended but no follow-ups were received. After interviews were transcribed (Mulholland, 2014), we thematically coded the data using qualitative data analysis software (MaxQDA) (Sun Link, 2018, 2021; Middel et al., 2016). We analyzed the interviews to identify patterns and repetitions in the responses to generate themes. We created a codebook based on the phrases and terms that were repeated after the initial assessment. Quotes were then organized using codes and were subsequently categorized into related themes.

3. Results

First, we present results from the streetcar user survey, followed by decision-maker interviews. Then we discuss heat impacts, heat planning, heat information, and challenges that decision-makers face and opportunities available for addressing heat.

3.1. Streetcar user survey

A total of 98 survey responses were received between October 2021 and January 2022, with 84 of those surveys completed fully and analyzed. Of those 84 survey takers, 51.28 % of participants were females, 41 % were males, 3 % identified themselves as non-binary/third gender, and 5.13 % preferred not to answer the gender question. The majority of respondents (73 %) stated that they were between the ages of 20 and 40, 13 % said they were between the ages of 40 % and 61 % said they were under the age of 20 %, and 7 % indicated they were over 60. The users surveyed reported annual household incomes, including 20 % at less than $20,000, 32 % between $20,000 and $40,000, and 32 % at more than $60,000.

Half of the survey respondents reported that they use the streetcar to go to school. Less common reasons for using the streetcar among survey respondents were entertainment (25 %), shopping/errands (19 %), going to work (15 %), and connecting to other transit (12 %). The users surveyed reported using the streetcar daily (20 %), weekly (24 %), monthly (11 %), several times a year (31 %), and less than once a year (15 %).

In arriving at the Sun Link streetcar stops, a majority (80 %) reported that they usually walk. Less common methods of getting to the streetcar stops included car (16 %), bus (14 %), bike (10 %), and ride share (4 %). Nearly half of the respondents (47 %) reported waiting between five to ten minutes at the streetcar stop while 33 % of respondents reported waiting more than ten minutes, and 21 % reported waiting less than five minutes.

Even though the survey was conducted during Tucson's cooler season, a majority of respondents (85 %) stated that they have felt hot at a streetcar stop at some point. Further, 31 % of respondents described their thermal comfort at some point as hot, 26 % as warm, 18 % as very hot, and 8 % as extremely hot. Only 14 % described their thermal comfort level as neutral.

When participants were asked about how often they used the streetcar when temperatures get hot, only 33 % reported that they would continue to use itas normal. Most users (40.00 %) reported that they would use the streetcar less often, and 23 % reported that they stopped using it altogether when it was hot. When asked what temperature threshold they would stop riding the streetcar, the majority of survey respondents (53 %) considered not riding at 100 ˚F and above, while 29 % considered not riding the streetcar at 110 ˚F and above.

When participants were asked about health issues after a streetcar ride, 34 % of respondents reported they had experienced a headache, a possible sign of heat stress. In addition, users also reported experiencing dehydration (29 %) and fatigue (18 %), additional possible signs of heat stress. Among all of the strategies to stay cool, respondents reported using shaded stops (65 %), drinking more fluids (60 %), and spending less time outside waiting for the streetcar (43 %).

Streetcar users were also asked which streetcar stop design features they liked the best (see Fig. 1), and the top responses included shade (24 %), benches (23 %), and nearby trees and vegetation (19 %). Participants were also asked if adequate shading exists at the stops, with 54 % of the respondents reporting the stops do not have adequate shading, and 28 % were unsure. They were also asked which features would make the stops more comfortable (see Fig. 1). Top answers included additional shade structures (30 %), additional trees and vegetation (26 %), and use of materials that get less hot (25 %). Users were also asked if the COVID-19 pandemic had changed their use of the streetcar a majority (60 %) stated that it had changed their ridership.

3.2. Decision-makers interviews

The semi-structured interviews with five streetcar decision-makers generated themes on a variety of topics. These were coded and organized into four themes: 1) heat impacts, 2) heat planning, 3) heat information sources, and 4) challenges and opportunity. The interviews provided insight into how the Sun Link Streetcar and its users are affected by the heat. Generally, participants were consistent in their support of a heat stress safety training program, their desire to enhance shade, and their aspirations to offer users better heat-coping mechanisms. However, there were differences regarding how best to improve the outdoor thermal comfort of users at stops, specifically related to the streetcar stop design.

3.2.1. Heat impacts

All interview participants discussed the heat impacts of the streetcar system. Two of the managers reported observing the heat impacts on streetcar users waiting at stops. One of the managers mentioned, “Everyone has an expectation there's no temperature control in the outdoor platform.” They said, “If passengers don't have to stand at the station stop too long, normally heat will not impact most people.” One of the participants also mentioned, “Stops are outdoors, so I don't think we have considered any type of system that would keep users cool while they are waiting.”

Streetcar decision-makers discussed heat impacts to their employees. One of the managers remarked that the extreme heat would influence the behavior of their employees who frequently visit the stops. They noted, “Technicians will come in early in the morning or at nighttime to try to beat the heat.”

Three of the managers also explained how the extreme heat initially produced problems with the streetcar infrastructure since the trains were built in Oregon and were not tailor-made for the extreme heat. One manager revealed, “There have been times where excessive heat can cause some mechanical issues, probably minor delays sometimes.” Another participant also noted that the streetcar is suffering from the

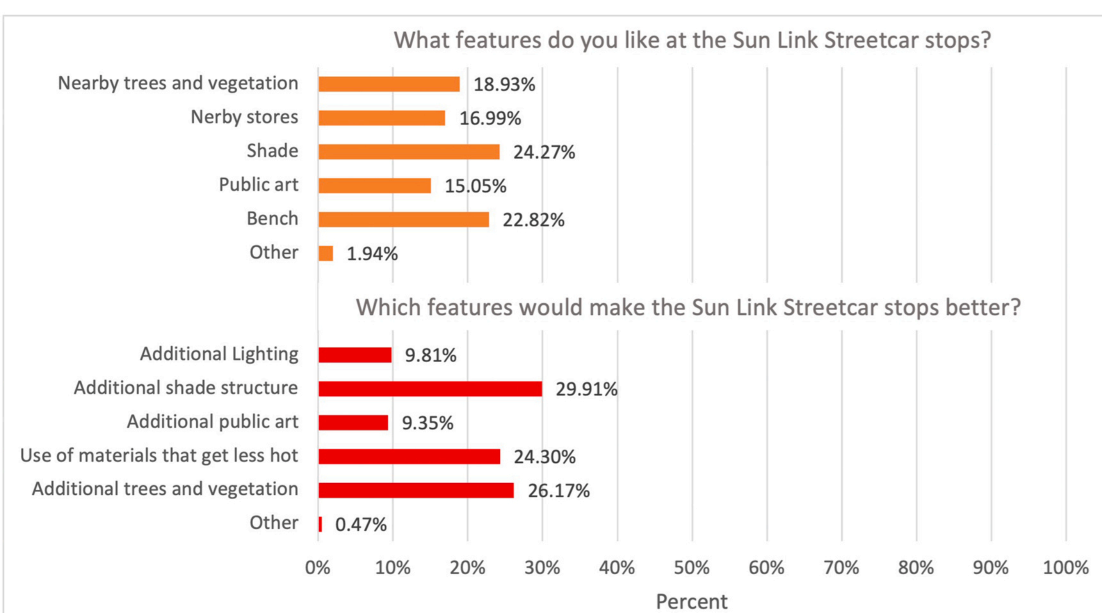

Fig. 1. Survey results on streetcar design features.

impacts of extreme heat. "I know our all-CS line [overhead wires] will have more sagging than normal in the heat." Despite the fact that one of the managers mentioned how they were having difficulty with streetcar infrastructure and heat toward the end of the interview, they did not consider heat to be a serious issue, saying, "We know how to adjust to heat. Because this is where we live. So we know what we need to do."

3.2.2. Heat planning

In their responses, all interview participants highlighted heat resilience strategies, including both heat mitigation and heat management—although without referring to them by that terminology. All five managers mentioned heat management strategies in their interviews.

The heat safety training program was regarded by all interviewees as one of the heat management strategies utilized by Sun Link. One participant mentioned, "We post safety advice regarding heat, telling employees to make sure they're taking care of themselves. There is a section regarding heat in this training, and employees are learning about the effects of extreme heat." Two of the managers also specifically discussed the details of heat exhaustion and heatstroke symptoms within employee training. A participant shared, "All of us are trained in detecting signs of heatstroke and heat exhaustion." Two of the participants also discussed having signage on the information board in the employee room along with weather information, especially during extreme heat periods.

According to the information that managers shared with during the interview, there would be no schedule changes due to extreme heat. As noted by managers, the streetcar operation is subject to change depending on the University of Arizona's calendar to serve college students. Three of the managers explained that speed restrictions were implemented in transition areas to mitigate the heat effect on the streetcar system. All of the managers agreed that having an extra HVAC unit on top of the streetcar to pump cold air to the wires was a helpful option. As one manager explained, pumping some of the cool air out of the streetcar helped in addressing some challenges that the streetcar infrastructure had with heat at the beginning. "These extra HVAC units cut the temperature by 40%, so it was one of our learning experiences in the heat, and we're trying to address the sagging concerns with cool air and speed restriction."

All of the participants stated that they encourage their staff to stay hydrated, especially when it warms up. They provide ice water, and all employees are permitted to bring a water bottle with them. One of the managers noted, "On certain days where we have seen excessive heat, we simply make sure that we sort of friendly reminds our operators to remain hydrated, and they're quite good at doing that." When it becomes too hot, one of the managers says they try to give their employees more rest time. "We make sure that the daily advisory sheet reminds employees that there's an excessive heat warning today; they should make sure that they have extra water on them and try to wear a hat."

One of the managers also addressed modifying the working hours for technicians. "When it's hot outside, we ask our technicians to come in early in the morning or late at night to attempt to avoid the heat." One of the interviewees also noted that they advise their staff not to stand outside for too long and to move somewhere cooler, such as inside the streetcar. They added, "For changing the operator, our personnel are not walking, so we provide a golf cart so that they can just drive there, swap, and then come back, and that's pretty much how we deal with the heat."

Four of the participants stated that more shade at the stops would be beneficial in reducing heat. "Depending on what time of day it is, even with some of the covering, you can't hide from the sun at some of the station stops, so would additional shade for people be useful? Absolutely, it would be," one of the managers remarked. One of the managers discussed several additional ways to increase the cooling effects. They suggested that options such as having indoor stations could be pleasant but also quite expensive. Another alternative they mentioned was installing a misting system to provide evaporative cooling as well as providing drinking fountains at stops for streetcar users.

3.2.3. Heat information sources

Two of the interviewees mentioned that they use the local news channel to monitor the weather on a regular basis. One of the managers reflected that utilizing the National Weather Service would be a more helpful option that was not currently being done. "It would be useful every morning the Operations Control Center will look at the National Weather Service prediction and if we have any excess heat warnings issued by them." Aside from the news and National Weather Service, two interviewees mentioned that having more heat information from the City of Tucson would also be helpful.

3.2.4. Challenges and opportunities in addressing heat

Managers acknowledged several challenges, but because of the timing of the interviews, COVID-19 was highlighted as one of the top challenges for the Sun Link Streetcar by all interviewees. "During the pandemic, our ridership dropped dramatically, and during the mass closures of businesses, ridership was very low, distress was quite high, and it was difficult for users to keep masks on in the stops, especially during the summer."

Another challenge highlighted by three of the participants was a lack of resources. "I believe our hands are tied for the time being, but the city does have to say that adding more shade or anything that would give any improvements to the station would be something the city would have to consider."

Another challenge mentioned by one manager was a lack of knowledge about cooling centers, which is particularly relevant for streetcar users who are experiencing homelessness. "I think the city could do a better job of advertising cooling areas because we do have cooling areas set up throughout the city during the hotter months of the year, and the city could advertise where those cooling centers are, especially with the homeless population because they don't always get to go anywhere with air conditioning."

4. Discussion

Heat is characterized as a "silent killer" because, unlike other disasters, it does not cause visible damage as often (Carroll, 2002) but does affect the infrastructure and the ridership of public transportation. According to our findings, the majority of Sun Link Streetcar users feel hot at the stops, and decision-makers acknowledge heat issues—particularly for their employees—but also for riders. Decision-makers reported needing more resources to address this issue. Streetcar decision-makers agreed that streetcar stops offer adjustable shades, which may help with the heat. The most often reported design components that provide perceived cooling advantages to public transport users are shade structures and trees in similar studies (Dzyuban, 2020; Middel and Krayenhoff, 2019; Lenzholzer et al., 2018). Most streetcar users agreed that more shade and greenery at the stops would help them to feel more comfortable.

Decision-makers discussed various heat resilience techniques in their interviews and considered heat to be a serious health threat, as indicated by their approval of the heat safety training program. A traveler's mode of transportation is influenced by the weather (Jendritzky and Nübler, 1981). Weather can impact transit service quality by causing schedule changes, influencing the time it takes to travel to stops, and affecting the entire journey duration (Grahn et al., 2021; Dzyuban et al., 2017). Of the 80 % of the survey respondents who walk to the stops to use the streetcar, many mentioned they waited at stops between five to ten minutes and sometimes for more than ten minutes. Waiting periods are seen to be more challenging by transit users in uncomfortable circumstances such as adverse weather and unsafe locations (Johansson et al., 2014).

Heat exposure on public transportation is determined by travel time and wait time (Fraser and Chester, 2017; Dzyuban, 2020). Google Maps estimates it takes six to thirteen minutes to walk across the nearby university campus. So, Sun link streetcar riders can potentially be exposed to heat for 11–23 min. According to the CDC (Mulholland, 2014), a body temperature of 106 °F or above may induce heat exhaustion in 10–15 min. More than half of survey participants stated they would stop using the streetcar beyond 100 °F. The same proportion of streetcar riders reported heat-related illnesses such as headaches, dehydration, and fatigue (Chow et al., 2012b). These conditions may persist for hours, affecting concentration, productivity, and requiring recovery time. If untreated or exposure continues, they may lead to severe health complications (Dzyuban, 2020). Heat exposure to public transportation users already results in reported heat-related illnesses, and is also impacting rider preferences, potentially decreasing overall ridership as temperatures continue to rise due to climate change and the urban heat island effect. While it was found that fixed-guideway transit systems such as the Sun Link Streetcar can have an overall positive impact on health by promoting physical activity, our study has revealed that riders in hot locations like Tucson also experience a high rate of heat-related illnesses (Delgado-Ron et al., 2022).

Streetcar managers mentioned speed restrictions (reducing speed) and adding more HVAC systems on top of the streetcars to help with the heat. Portland Streetcar used a similar procedure in 2021 to prevent sagging overhead wires due to heat (Miles and Huberman, 2016). The Sun Link Streetcar does not have a heat awareness program for its users, but it utilizes the forecasted weather from local news to notify and educate employees about extreme heat. We sent out the survey throughout the cool season (October 2021–January 2022), yet 80 % of the users remember experiencing heat exhaustion, and (85.05 %) of respondents reported feeling hot at the stops.

The streetcar decision-makers did note the success of their heat awareness training for managers, which includes recognizing heat stress for the streetcar employees. The managers could extend this heat awareness training further to help increase awareness of the heat exhaustion that some of their riders are experiencing. The streetcar decision makers also reported requiring more resources for activities such as this. Therefore, we also recommend that the streetcar system receive additional resources to help address the heat stress of their users. Some cities, such as Las Vegas, Nevada, have begun annual campaigns to raise awareness of the dangers of the summer heat for their transit users (RTC, 2022). The Las Vegas transit service schedule has also been modified as part of the beat the heat initiative. Additionally, they identify high risk groups and provide a list of precautions to take in order to reduce the risk of heat-related disease and harm, such as planning activities for the morning or the evening and dressing in light, loose fitting clothes (RTC, 2022).

Due of the timing of this research, decision-makers highlighted the challenges of COVID-19 on transit systems. More than 50% of streetcar users stopped using the streetcar because of COVID-19. During the interview, decision-makers mentioned it was challenging for users to wear masks while waiting for transportation, particularly in the summer due to heat. The combination of heat and COVID-19 in 2020 and 2021 caused more concern for the healthcare system (Vaismoradi et al., 2013). Outdoor workers and homeless are more likely to contract COVID-19 (Vaismoradi et al., 2013). Heat risk was higher for unacclimated workers and volunteers at outdoor COVID-19 vaccination sites (Nikolopoulou et al., 2001a), therefore incorporating heat resilience would help to reduce COVID-19 and heat mortality overlap (Vaismoradi et al., 2013; Jendritzky and Nübler, 1981). Some of the decision-makers mentioned that providing more information about the location of cooling centers around the city would decrease heat stress, especially for homeless people. A common method during extreme heat is to employ cooling centers, a cool site, or an air-conditioned building designated as a safe area to mitigate the heat stress (Iseki et al., 2007; Delgado-Ron et al., 2022).

5. Conclusion

This study investigated the impact of thermal comfort perceptions on transit users' ridership experience and health, as well as their design element preferences for the stops, and the perceptions of the operators of the Sun Link Streetcar in Tucson, Arizona. Survey results revealed that 82.4 % of streetcar users reported feeling hot and over half reported experiencing heat-related illness while at the streetcar stops, emphasizing the urgent need to mitigate heat stress for transit users. Additionally, 56.08 % of streetcar users identified the addition of more shade and greenery as a potential solution to improve their thermal comfort. Decision-makers acknowledged heat risk during interviews and noted progress in addressing heat risk for streetcar staff, through programs such as the heat safety awareness training. Decision-makers also and reported needing additional resources to address the problem for streetcar users, particularly vulnerable users such as those experiencing homelessness.

This study emphasizes the need to prioritize heat resilience and thermal comfort in public transportation planning. Decision-makers can use the findings from this study to demonstrate the need to address heat resilience and thermal comfort in transportation planning in the face of a rapidly warming climate.By addressing both heat mitigation and management strategies, transit systems can provide a more thermally comfortable experience for their users, ultimately improving public health and wellbeing.

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Declaration of Competing Interest

The authors whose names are listed below certify that they have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

The authors certify that this manuscript has not been submitted to, nor is under review at, another journal or other publishing venue.

The authors certify that they have no affiliation with any organization with a direct or indirect financial interest in the subject matter discussed in the manuscript.

Appendix A. Survey questionnaire

1. Why do you usually use the Sun Link streetcar? (Select all that apply)				
□ Work	□ School	□ Connection Transient	□ Shopping/ Errands	□ Entertainment
2. How do you usually arrive at the Sun Link streetcar stops? (Select all that apply)				
□ Walking	□ Biking	□ Car	□ Bus	□ Ride Share
3. About how often do you use the streetcar? (Select one)				
□ Daily	□ Weekly	□ Monthly	□ Several times a year	□ Less than once a year

4. How long do you usually wait at the Sun Link streetcar stops?				
□ 1–5 min	□ 5–10 min	□ 10–15 min	□ 15–20 min	□ More than 20 min
5. Have you ever felt hot at the Sun Link streetcar stop?	□	□ Yes	□ No	□ Unsure
6. How would you describe your normal comfort level at the Sun Link Streetcar stops? (Select one)				
□ -4 Very cold	□ -3 Cold	□ -2 Cool	□ -1 Slightly cool	□ 0 Neutral
□ + 1 Warm	□ + 2 Hot	□ + 3 Very Hot	□ + 4 Extremely Hot	
7. Do you change the way you use the Sun Link streetcar when it gets hot? If yes, what are some strategies you have used to stay cool? (Select all that apply)				
□ No, I continue to use the streetcar as normal.				
□ Yes, I use the streetcar less often.				
□ Yes, I stop using the streetcar when it is too hot.				
□ Yes, other (Select all that apply):				
□ Drink more fluids				
□ Use a sun umbrella				
□ Wear summer clothes (e.g., long-sleeve shirts and hat)				
□ ride early or later				
□ Walk or bike in the shade				
□ Prefer to use shaded stops				
□ Spend less time outside waiting for streetcar				
8. How would you describe your normal destination after riding the streetcar? (Select all that apply)				
□ Outdoor space without shading	□ Shaded outdoor space			
□ Indoor space with A.C.	□ Indoor space without A.C.			
9. What features do you like at the Sun Link Streetcar stops? (Select all that apply)				
□ Nearby trees and vegetation	□ Nearby Stores	□ Shade		
□ Public art	□ Bench	□ Other		
10. Which features would make the Sun Link Streetcar stops better? (Select all that apply)				
□ Additional lighting	□ Additional shade structure	□ Additional public art		
□ use of materials that get less hot	□ Additional trees and vegetation	□ Other		
11. At what temperature you would consider not riding the Sun Link streetcar? (Select one)				
□ I would continue riding the streetcar regardless of the temperature.				
□ 80 ˚F +	□ 90 ˚F +	□ 100 ˚F +	□ 110 ˚F +	
12. Have you ever had one of these health symptoms during or after your Sun Link streetcar ride?(Select all that apply).	□ None	□ Headache	□ Dehydration	
□ Fatigue	□ Nausea	□ Heat Stroke		
13. Do the Sun Link streetcar stops have adequate shading?	□	□ Yes	□ No	□ Unsure
14. Has COVID-19 changed your use of the Sun Link streetcar?	□	□ Yes	□ No	□ Unsure
15. Zip code:				
16. Age:	□ < 20	□ 20–40	□ 40–60	□ > 60
17. Gender:	□ Male	□ Female	□ Non-binary/3rd gender	□ Prefer not to answer
18. Clothing:	□ Light summer clothes	□ Jackets	□ Others	
19. Household income	□ Below $20,000	□ $20,000–$40,000	□ $40,000–$60,000	
	□ $60,000–$80,000	□ $80,000 or over	□ Prefer not to answer	

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